Novel Visualization Algorithms and Production Visualization Tools for Adaptive Mesh Refinement Data

G. H. Weber[1], H. Childs[2], E. Deines[3], C. Garth[3], J. Meredith[4], D. Pugmire[4], B. Whitlock[2], E. Wes Bethel[1]

[1]Lawrence Berkeley National Laboratory; [2]Lawrence Livermore National Laboratory; [3]University of California, Davis; [4]Oak Ridge National Laboratory

Summary

Adaptive Mesh Refinement (AMR) is a highly effective simulation method for spanning a large range of spatiotemporal scales like those encountered in astrophysical simulations that must accommodate ranges from interstellar to sub-planetary. Historically, AMR data have not been supported well, if at all, in visual data exploration applications. As a result, AMR code teams had no choice but to maintain in-house applications, such as ChomboVis, for AMR visualization. The Department of Energy's (DOE's) Science Discovery through Advanced Computing (SciDAC) Visualization and Analytics Center for Enabling Technologies (VACET) has extended VisIt, an open source visualization tool that accommodates AMR as a first-class data type, in an effort that consists of research in novel AMR visualization algorithms, such as AMR streamlines, as well as visualization infrastructure engineering. As a result, VisIt is now the premier, production-quality, parallel-capable AMR visual data analysis tool. The Applied SciDAC Applied Partial Differential Equations Center for Enabling Technologies (APDEC) and its collaborators have adopted VisIt for all their AMR visualization needs, supplanting ChomboVis, their in-house application, resulting in significant cost and labor savings.

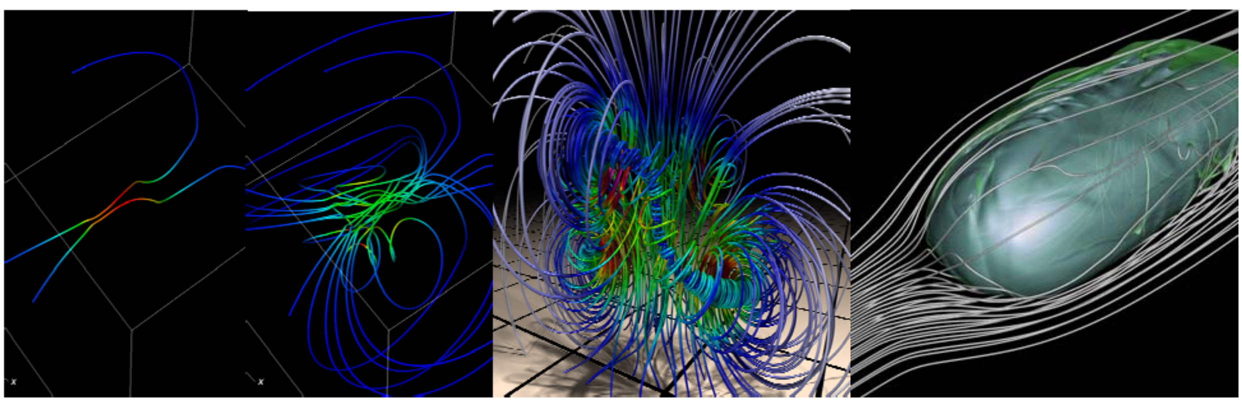

Figure 1: (Left) Calculating streamlines without considering the AMR hierarchy does not detect finer AMR levels that represent an area within the domain at higher accuracy. Instead, streamlines stay completely in the coarsest level. Considering the AMR hierarchy during streamline calculations makes it possible to detect the presence of finer resolution levels and always use the most accurate data representation available. (Center) Production-quality visualization of an AMR vortex core merger simulation for a brochure. (Right) Using streamlines for visualizing an AMR solar wind simulation.

Adaptive Mesh Refinement (AMR) techniques combine the compact, implicit structure of regular, rectilinear grids with the adaptivity to changes in scale of unstructured grids. VisIt is an open source visualization tool that accommodates AMR as first class data type. VisIt offers a rich set of production-quality functions for parallel visualization and analysis of complex data sets on

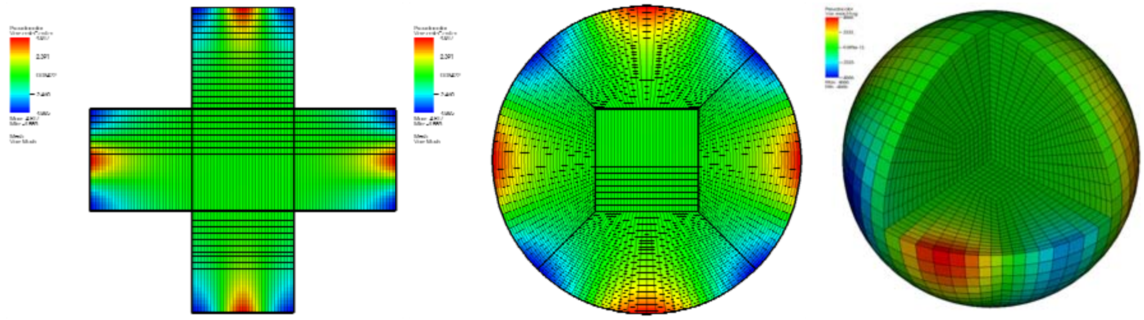

Figure 2: VisIt's mapped grid support for AMR data lets users switch between parameter space (left) and physical space (center). It supports both 2D (left, center) and 3D (right) mapped AMR grids, which is important for fusion and climate science applications.

parallel platforms, making it an ideal candidate to replace specialized AMR visualization tools.

AMR visualization is challenging since coarser information in regions covered by finer patches is superseded and replaced with information from these finer patches. During visualization, it becomes necessary to manage selection of which resolutions are being used for any given visualization operation. Furthermore, it is difficult to avoid discontinuities at level boundaries, which, if not properly handled, lead to visible artifacts in visualizations.

Among our AMR visualization research efforts is a novel streamline calculation algorithm. Working closely with our APDEC stakeholders, we are developing AMR-aware streamlines in VisIt (Figure 1). As outlined above, the major algorithmic challenge lies in detecting the presence of finer AMR hierarchy levels, ensuring that streamlines are computed with the highest available resolution data, and using correct interpolation at the transition between coarse and fine levels. The involvement of APDEC researchers in this project ensures that streamline calculations meet stringent accuracy requirements.

Our AMR visualization work is also focused on specific application domains – fusion and computational astrophysics who are APDEC stakeholders – to ensure that the new algorithms we have and continue to develop meet their needs. VisIt serves as our primary research and development infrastructure for parallel AMR visualization. As such, new research quickly transitions from prototype to deployment in a production-quality end-user tool.

We are also leveraging VisIt's capability to deform a computational grid or grid hierarchy by a vector variable. This ability makes it possible to view simulation data both in computational parameter space as well as in "mapped" physical space. Working with APDEC researchers, we extended VisIt's Chombo file reader to test for the existence of mapping information. Further, we added macros that simplify accessing this functionality and allow users to switch seamlessly between computational space and physical space views (Figure 2). Switching between these views is essential for debugging purposes, since it supports viewing both the logical grid structure of simulations, such as the connectivity between the five grids on the left side of Figure 2, as well as seeing results in a physically meaningful context.

Close collaboration with APDEC allows us to develop this visualization capability in conjunction with the corresponding simulation codes, ensuring that appropriate visualization capabilities are deployed shortly after simulation code release. The ability to handle mapped grids is important to application scientists in climate (e.g., the cubed sphere on the right hand side of Figure 2) and fusion applications, who were recently able to view their AMR simulation results in mapped space for the very first time.

For further information on this subject contact:
Name: Gunther H. Weber.
Organization: Lawrence Berkeley National Laboratory.
Email: GHWeber@lbl.gov
Phone: (510) 486-5871

Note: This work was funded in part by the SciDAC2 Visualization and Analytics Center for Enabling Technologies and ASCR's Visualization Base Program by the Director, Office of Science, Office of Advanced Scientific Computing Research, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.